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THE PROBLEM OF BURNT TUNA IN THE HAWAIIAN FISHERY

Jean I. Cramer,[1] Richard S. Shomura, and Heeny S. H. Yuen
Southwest Fisheries Center
National Marine Fisheries Service, NOAA
Honolulu, Hawaii 96812

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Introduction

Tunas represent the most important economic fishery resource in the Hawaiian Islands. In 1976 the total domestic tuna catch was 5,550 metric tons (MT) with an ex-vessel value of $6.4 million (U.S.). While skipjack tuna, Katsuwonus pelamis, was the most important species in the tuna catch, making up approximately 80% of the landings and 60% of the value, the importance of the other tuna species, especially yellowfin tuna, Thunnus albacares, and bigeye tuna, T. obesus, has increased markedly in recent years. Table 1 provides catch statistics of the tunas for the 1962-76 period. The increase in landings of the combined yellowfin tuna, bigeye tuna, albacore, T. alalunga, and kawakawa, Euthynnus affinis, catch has been due primarily to the expansion of the handline fishery for tunas and the increase in recreational fishing. Recreational fishing in Hawaii has a unique aspect in its operation, wherein the economically valuable species are very often sold through commercial outlets. Basically the operation is still considered recreational fishing since the fishers do not depend upon fishing as a basic means of livelihood.

Economically, the handline fishery for tunas show a potential of tremendous growth if the problem of burnt tuna can be overcome. The present report provides (1) a brief description of the various types of flesh quality problems faced by the tuna industry, (2) a brief description of the handline and troll fisheries in Hawaii, and (3) results of a current study being undertaken by the Honolulu Laboratory (Southwest Fisheries Center, National Marine Fisheries Service) and the University of Hawaii to determine the causative factors involved with burnt tuna and to seek solutions to this costly problem.

Flesh Quality Problems in Tuna

Burnt tuna is raw tuna which is paler and softer than normal. The color may vary from slightly pale (borderline burn) to almost white. The area affected varies from 5% to 100% of the edible meat of the fish. In cases of partial burn the area affected is the part of the meat which is closest to the spinal column. The condition occurs most frequently in large tunas (yellowfin and bigeye) from 45 to 136 kg caught in shallow water. The fish is edible but is less desirable for raw consumption and therefore commands a lower price.

Burnt tuna appears to be similar to a condition in pork known as Porcine Stress Syndrome (PSS) (Hugh 1976). Both conditions involve stress, high body temperatures, acidity of muscle, and result in pale and soft muscles.

Tuna, along with saury, seerfish, butterfly kingfish, and mackerel, normally contain large amounts of free histidine in their muscle tissue. Under certain conditions the free histidine may be decarboxylated by some bacteria to produce high levels of histamine (Geiger 1944; Kimata and Kawai 1953; Ferencik 1970).

Growth of histamine producing bacteria was optimum at acidic pH (5-6) and moderately high temperatures (20°-30°C) (Kimata and Akamatsu 1955).

One of the best methods of retarding bacterial histamine formation in fish is storage below freezing (Brown and Arnold[2]).

Scombroid fish poisoning clinically resembles histamine poisoning intoxication, however, controversy exists as to whether histamine ingested orally is toxic (Halstead 1967; Granerus 1968; Douglas 1970). A number of reports indicate that histamine taken orally by human subjects is not toxic (Granerus 1968; Douglas 1970; Hardy and Smith 1976). Certain diamines (e.g., putrescine) may alter absorption of histamine (Parrot and Nicot 1965; Irnistea 1973). Alterations of conditions of the intestinal tract due to consumption of highly seasoned hot dishes or alcohol may cause increased absorption of histamine (Geiger 1955). Whether histamine is the sole toxic factor or not, it is generally found at high concentrations in foods causing scombroid poisoning (Simidu and Hibiki 1955; Ferencik 1970).

Honeycombing is a condition which becomes noticeable after precooking in canned tuna. It is characterized by irregular holes or pits penetrating more or less deeply into the tissue. The size of the honeycombed pits may vary from small pits to pits covering extensive areas. A transverse section of an extensively honeycombed area has an appearance suggestive of an empty honeycomb (Hillig 1956). Fish in this condition are rejected for human consumption.

Otsu (1957) reported that honeycombing in Hawaiian skipjack tuna resulted from delayed refrigeration and was independent of sexual maturity or size of fish. The rate of honeycombing increased with higher seawater temperatures. When allowed to decompose to varying stages yellowfin tuna and skipjack tuna with honeycombing had much higher histamine levels than similar fish without honeycomb (Williams 1954).

Studies presently in progress, however, indicate that honeycombing and histamine production are not interdependent. Fish incubated in the presence of antibiotics exhibit honeycombing but do not have high histamine levels (H. Frank, Department of Food Science, University of Hawaii, Honolulu, Hawaii 96822, pers. commun.)

Green tuna occasionally occurs in precooked tuna when the normal pink color fails to develop. The cooked meat takes on a tannish-green color and is rejected as unsuitable for canning (Brown, Tappel, and Olcott 1958). The pink has been shown to be due to a hemochrome derived from the myoglobin in the loin (Brown and Tappel 1957) and the green is mostly hemichrome (Brown et al. 1958; Naughton, Zeitlin, and Frodyma 1958). The condition does not appear to be related to oxygen starvation during landing (Naughton et al. 1958). Green tuna is most frequently found in yellowfin tuna.

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[2]Brown, W. D., and S. H. Arnold. 1957. Histamine (?) toxicity from fish products. Unpubl. manuscr. Institute of Marine Resources, Department of Food Science and Technology, University of California, Davis, California.

The condition is not recognizable in the raw state and therefore much effort is wasted in processing the fish. Nagaoka, Yamagata, and Horimoto (1971) have developed a method for prediction of green tuna. They report that the determination of trimethylamine oxide and trimethylamine contents in the raw dorsal muscle of yellowfin tuna yields a predictive accuracy of 96%.

Description of Fisheries

The problem of burnt tuna seems to be most serious with tuna caught by trolling, serious with tuna caught on night handlines, and minor with tuna caught on longlines. The problem, in fact, was first brought to the attention of the National Marine Fisheries Service by recreational fishers who troll in the Kona, Hawaii area.

Recreational fishers use rods and reels as fishing gear. They troll lures from a wide variety of boats which range in length from 4 to 18 m. The prime target species are the larger game fish, including yellowfin tuna; blue marlin, *Makaira nigricans*; striped marlin, *Tetrapturus audax*; black marlin, *M. indica*; shortbill spearfish, *T. angustirostris*; sailfish, *Istiophorus platypterus*; mahimahi, *Coryphaena hippurus*; and wahoo, *Acanthocybium solandri*. Trolling speed is a matter of individual preference and generally ranges from 10 to 20 km/h. Surface water temperatures in the Kona area where the burn problem is most serious vary between 24° and 29°C.

Lines of various sizes are used on the reels. The heaviest line used has a breaking strength of 59 kg or less. Fishers use lighter lines to make fishing more sporting and challenging. Fighting time, the interval between the taking of the lure by the fish and the boating of the fish is highly variable. In the catching of yellowfin tuna, fighting time is partly a function of line strength and fish size. In a sample of 44 yellowfin tuna caught on line with a breaking strength of 36 kg or less, fighting time ranged from 4 to 198 min with a mean of 46 min. The fighting time in a sample of 29 yellowfin tuna caught on line of 23 kg or less breaking strength ranged from 5 to 329 min with a mean of 93 min. Fish in this sample weighed 46.3-115.2 kg. These variables do not account for all of the variability in fishing time. Fishing technique, skill of fishers, vitality of the fish, weather conditions are conceivably other factors.

Another fishery in which burnt tuna is a serious problem is the night handline fishery for tunas. To our knowledge this highly effective method of fishing for tunas is used only on the island of Hawaii and in the Philippines (E. Oswald, South China Seas Fisheries Development and Coordinating Programme, Makati, Rizal, Philippines, 1976, pers. commun.). Until 1976 this method of fishing in Hawaii was limited to a small area off Hilo, Hawaii. Night handline fishers presently fish in areas off the coastline of the entire southern half of the island of Hawaii.

Fishers time their trips to arrive on the fishing grounds at sundown. Upon arrival the engine is shut down and a parachute is attached to the bow and lowered into the water. The parachute is 7.2 m in diameter. Over surface lights and/or an underwater light are turned on. Typically 25- and 50-W incandescent bulbs are used for the above surface and underwater lights, respectively.

The stage is finally set for fishing with the tossing overboard of a few kilograms of chum consisting of chopped up mackerel scad, Decapterus pinnulatus. If fishing is in an area where the squid, Notodarus hawaiiensis, is expected to be available, then fishing for squid to be used as bait is begun. Otherwise, mackerel scad is used for bait and fishing for tuna commences.

The handline for tuna fishing consists of a hook of Japanese design (Tonkichi BKM No. 54[3]) at one end attached to a leader of about a meter of 7-strand stainless steel wire of 227-kg (500-lb) test, a lead weight of 227-397 g (8-14 oz), and 110-130 m of line which is usually polypropylene rope either 0.95 cm (3/8 in.) or 0.79 cm (5/16 in.) in diameter. At the start of fishing three handlines are set, one at the bow, one at the stern, and one amidship. As soon as the tuna start biting one line is removed and only two lines are fished. The baited hooks are lowered 20-30 m below the surface and held at that depth by securing the handline to the boat with a restraining line. The restraining line usually breaks when a tuna takes the hook. The restraining line has a breaking strength of about 45 kg (100 lb). This high breaking strength is used to increase the probability that the tuna will be securely hooked when it strikes.

After the restraining line breaks the tuna pulls out the handline at great speed. In a few seconds the drag of the increasing amount of line in the water slows the tuna down. When the outgoing line is slow enough the fisher grabs it and hauls the fish to the boat. When the fish is alongside, it is shot in the head, with either a handgun or bang-stick, hit again on the head with a baseball bat, gaffed, and pulled aboard. The catch is stored in ice or a mixture of ice and seawater.

The fishers leave the fishing ground to arrive at the auction site by 7 a.m. When fishing distant grounds they unload their catches at the nearest landing and truck the fish to the auction market.

The fishery catches bigeye tuna and yellowfin tuna primarily. Albacore is a third tuna species that is commonly caught. The contribution of these species to the handline fishery catch in weight and in value for the years 1973, 1974, and 1975 are listed in Table 2. The catch increased from 89.1 to 154.6 MT during these years, while the value of the catch increased at a slightly faster rate, from \$141.1 to \$327.5 thousand (U.S.).

Although the total tuna catch exhibited a continuous growth for the 3 years, the catches of the individual species fluctuated tremendously between years. In 1974 the bigeye tuna was almost twice as much as the

[3]Reference to trade names does not imply endorsement by the National Marine Fisheries Service, NOAA.

other 2 years; in 1975 the yellowfin tuna catch was more than three times the amount of the previous 2 years, and the albacore catch in 1975 increased by fiftyfold.

Serious economic losses due to burnt tuna are incurred by night handline fishers. Rebates on burnt fish were reported to range from 5% to 75% of the original auction price of the fish. Annual loss to night handline fishers due to burnt tuna has been estimated to be as high as 16% of their 1976 catch. Other economic losses include the shipping costs incurred and the inevitable poor reputation that the catch of the night handline fishery engenders due to the inconsistent quality.

Possible Causative Factor in Tuna Flesh Quality

Tunas are unique among fishes in that they are "warm bodied" and excess (above ambient water temperature) body temperatures up to 15°C have been reported. Body temperatures of decked bluefin tuna, *Thunnus thynnus*, were reported to be 5° to 15°C above ambient water temperature (Carey et al. 1971). Dizon, Brill and Yuen (in press) telemetered deep body temperature from free swimming skipjack tuna and found mean body temperatures to be higher than the ambient water temperature. Maintenance of body temperature above ambient water temperature is possible due to the presence of rete mirabile (Carey 1973).

The rete mirabile or "wonderful net" is a tissue composed of closely intermingled veins and arteries which permits the free flow of blood for transport of oxygen and other molecules but impedes the flow of heat from the body tissues to the gills. This conservation of body heat allows the tuna some of the advantages of a homeothermic animal. The higher body temperature increased the speed of metabolic reactions thus making possible a higher maximum swimming speed (Carey 1973). The ability to conserve heat and metabolize rapidly, however, produces the possibilities of overheating and rapid accumulation of metabolic by-products.

These relatively high body temperatures and high metabolic rates may be responsible for meat quality problems such as honeycombing, green tuna, and burnt tuna which are unique to tuna.

Devices to Reduce the Incidence of Burnt Tuna

Fishers have tried various methods to eliminate the burnt tuna condition from developing. Some insist that bleeding the fish before chilling is effective. Others advocate precooling the fish up to an hour by leaving it on deck at night or by placing it under burlap and running seawater over it during the day before placing it in the icebox. No method, however, meets with universal acceptance as the solution to the problem of burnt tuna.

In addition to the fishers' attempts three devices have been made to alleviate the problem. One of them has yet to be tried in Hawaii. Use of the other two has been very limited and, to our knowledge, discontinued.

On the assumption that the burnt condition was caused by improper cooling, the Honolulu Laboratory of the National Marine Fisheries Service distributed for trial a device to hasten the transfer of heat from the warmest part of the fish. The device which had the general shape of a comb consisted of five aluminum baking potato nails (11.7 cm long) held together in a row by an aluminum bar 1 x 1 x 14 cm. Three to five of these were inserted on each side into the dark red flesh that runs longitudinally beneath the lateral line in the section of greatest girth.

After one of the night handline fishers of Hilo tried the device, the others refused to use them. They based their refusal on the following reasons: inserting the devices would require too much time; the bars would not be flush with the body contours and would thus snag and tear the flesh; bacteria would be introduced; and, buyers would not buy fish with holes even if the holes are in flesh that is normally discarded. On the other hand, a small group of fishers in the Kona district have used the device until the supply was depleted due to attrition. Use of the device was reported by one fisher to have decreased the incidence of burnt tuna; this fact has yet to be substantiated.

In November 1975 a Mr. Ogawa of Daiichi Suisan Tsukyi, Japan, demonstrated the use of a metal rod to enhance the chilling of tuna. The demonstration was conducted on the island of Hawaii. The tail of the fish was cut off and a rod approximately 3 mm in diameter was inserted the full length of the vertebral column. The insertion was accompanied by deep incisions immediately posterior to the pectoral girdle and slashing of the gills to bleed the fish. Fishers have resisted using this method because of the work involved.

In September 1977 Mr. Haruyoshi Taniguchi, a recognized tuna expert from Japan, described a tool he has developed to instantly kill tunas. The tool consists of a coring cylinder and a stainless steel wire around which a copper spring is wrapped. The coring cylinder is used to bore a hole into the fish's head at the foramen (whitish spot on the middorsal line just above the eye). A length of wire is inserted through the hole and pushed through the spinal column at least 30 cm. This tool reportedly prevents burnt tuna by quickly destroying the nervous system and thus preventing any further stimulation of physiological activity. This method has not been tested in the Hawaiian Islands (Suisan Sekai 1977).

Study of Causative Factors of Burnt Tuna

A preliminary study was conducted in the fall of 1977 to investigate environmental and physiological factors causing the burnt tuna condition and to investigate the similarities of burnt tuna to PSS in swine.

Data were collected at the Hilo fish auction and on a number of night handline boats. Chilling methods used by individual night handline boats were noted whenever this information was volunteered. The senior author made nine trips on seven different boats. The size of the chill box and pounds of ice on board were recorded for each trip. When a large tuna was caught a blood sample was taken by cardiac puncture and the fish was labeled by clamping an ear tag on the pelvic fin.

Immediately after catching and prior to auctioning the superficial and deep muscle temperatures were taken by inserting an 11 cm probe attached to a telethermometer through the skin of the fish along the midline approximately 11 cm posterior of the pectoral fin. Superficial temperatures were taken at a depth of 1/2 cm and deep temperatures were taken at a depth of 11 cm unless the backbone prevented insertion to that depth. Sex was recorded if the belly was slit and the gonads were exposed at the time of auction. Observations were made of all large tuna which were cut on the auction block. The head and tail were cut off and then the fish were quartered. If burn was present, it was recorded.

Samples of tuna meat were obtained at the Honolulu fish auction. These samples were subsequently classified by the researcher as badly burnt, burnt, or not burnt (normal). Two-gram sections of these samples were placed in 10ml of distilled water and ground up. The pH of these homogenized samples was then determined. Samples of burnt and normal tuna were assayed for lactate and cultured to determine general bacteria levels.

Samples were also obtained from various parts of a small yellowfin tuna which died during a stress experiment at the Kewalo Research Facility. The pH of these samples was determined using the method described above.

Analysis of variance was used to determine significance of temperature differences between chill techniques and between burnt and normal tuna. The volume of the blood samples collected was not adequate for analysis.

Chill methods

A variety of methods is used to chill fish on the night handline fishing boats. The methods vary in the kind and amount of ice used, mixture of the ice with seawater, location and number of cuts for bleeding, and amount of time the fish is on deck between catching and chilling. Cuts for bleeding were usually at the heart, the belly, or the tail.

Five methods of handling are described in Table 3. Deep and superficial temperatures of all tuna over 45 kg were taken at the Hilo auction from 20 September to 15 October 1977 (Table 4). The superficial and deep muscle temperatures of fish were analyzed to determine if significant differences in temperatures exist between chilling techniques (Table 5). Significant differences in superficial temperatures were found between various chilling techniques. Significant differences, however, were found only in the deep temperatures for two pairs of methods (A and D, C and D). The amount of ice carried is probably the most important difference between methods. Deep temperatures were also affected by the amount of time the fish were kept in the chill box. Fish caught early in the evening have a considerably cooler deep temperature than fish caught in the morning.

No significant differences were found between auction temperatures of burnt and normal fish which were quartered at the Hilo auction (Table 6).

Tissue acidity

The stress of catching may result in acceleration of biochemical activity which will lead to an abnormally low tissue pH, premature rigor mortis, short duration of rigor mortis, and early deterioration of tissue (Borgstrom 1961). Differences in pH of burnt and normal tuna from the Honolulu auction were observed (Table 7). Burnt fish appeared to be consistently more acidic than the normal fish.

Conclusions

Burnt tuna is a system which is the result of two classes of factors, physiological stress and postmortem handling, acting independently or in combination. It appears that physiological stress alone may result in a burnt condition. All methods of chilling including immediate rapid chilling on longline boats result in some percentage of burnt tuna. The burnt condition has been observed immediately after catching (V. Ohai, Oceanic International Corporation, Honolulu, Hawaii 96817, 1977, pers. commun.).

It is not clear whether postmortem handling alone may result in burnt tuna or whether prior physiological stress is a necessary precondition. In any case postmortem handling seems to influence the severity of the condition. High levels of bacteria were found in cultures from both burnt and normal tissue samples. The level of bacterial activity may be affected by handling.

It would be very desirable to create an objective classification system for burnt tuna both from a research and an economic point of view. A color wheel could be developed which would allow an objective classification system for degree of burn of quartered tuna. It may be possible to detect burnt tuna by use of a tissue pH probe. If good correlations are found among the color wheel, visual classification system, and internal pH taken by the probe, a reliable system of grading uncut tuna may be developed.

Further evidence is necessary to confirm that a malignant hyperthermia is involved. It is also possible that an injection of a buffer such as bicarbonate may be used to counteract the effects of stress.

Current efforts in burnt tuna research are concentrated in the following areas: (1) continued investigation of the effects of catching and chilling techniques on the incidence of burnt tuna, (2) investigations into biochemical, histopathological, and microbial differences between normal and burnt tuna immediately after catching and after chilling, and (3) development of an objective classification system for burn in whole uncut tuna.

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Table 1.--Tuna catch, State of Hawaii.

Year	Skipjack tuna		Yellowfin tuna		Bigeye tuna		Albacore		Kawakawa	
	Weight (MT)	Value (thousands of US$)	Weight (MT)	Value (thousands of US$)	Weight (MT)	Value (thousands of US$)	Weight (MT)	Value (thousands of US$)	Weight (MT)	Value (thousands of US$)
1976	4,445	3,827	840	1,673	197	825	27	40	41	23
1975	2,293	2,282	781	1,371	157	673	43	83	30	16
1974	3,374	2,676	523	983	187	731	9	15	16	9
1973	4,878	3,203	349	625	185	688	14	28	15	8
1972	4,953	2,949	375	560	229	684	8	12	17	7
1971	6,053	2,753	389	517	214	568	11	11	13	7
1970	3,335	1,497	320	499	216	510	9	11	8	5
1969	2,706	1,245	192	236	322	673	12	12	18	10
1968	4,229	1,540	188	204	256	499	10	8	13	5
1967	3,648	1,263	228	230	294	476	12	9	22	5
1966	4,258	1,404	228	215	346	483	9	6	13	4
1965	7,331	2,014	226	177	351	471	3	2	7	2
1964	4,094	1,222	227	185	380	493	4	3	16	6
1963	3,675	1,090	175	153	430	502	7	5	27	8
1962	4,272	1,174	180	143	554	598	8	4	6	2

Table 2.--Weight and value of tuna catch of night handline fishery.

	Weight (MT)			Value (thousands of US$)		
	1973	1974	1975	1973	1974	1975
Bigeye tuna	65.4	120.2	63.1	102.6	249.8	149.5
Yellowfin tuna	23.3	22.9	75.5	38.0	38.4	157.0
Albacore	0.4	0.2	16.1	0.5	0.2	21.0
All tunas	89.1	143.2	154.6	141.1	288.2	327.5

Table 3.--Methods of chilling used by handline fishers in Hilo, Hawaii.

Method A -	crush ice (not mixed with water)
	random cuts for bleeding (few, often none)
	5 min on deck between catching and chilling
Method B -	600 lb block ice mixed with seawater
	at least two cuts for bleeding
	5 min on deck between catching and chilling
Method C -	600 lb block ice mixed with seawater
	at least two cuts for bleeding
	longer than 5 min on deck
Method D -	300-450 lb of ice mixed with seawater
	no cuts for bleeding
	5 min on deck between catching and chilling
Method E -	300-600 lb of ice mixed with seawater
	random cuts for bleeding
	45 min truck ride (without ice) to auction market.

Table 4.--Fish body temperatures (°C) at time of auction.

Method	Number of fish	Average superficial temperature	Average deep temperature
A	17	14.9 ± 0.59	22.74 ± 1.68
B	44	15.26 ± 0.61	24.05 ± 0.77
C	14	17.20 ± 0.90	21.21 ± 1.43
D	21	19.50 ± 0.77	26.61 ± 0.75
E	6	19.80 ± 0.51	24.50 ± 1.82

Table 5.--Comparison of body temperatures by method of chilling (analysis of variance tests).

	Superficial temperature					Deep body temperature			
	B	C	D	E		B	C	D	E
A	0.49	2.30*	4.60**	4.85**	A	1.31	1.53	3.87*	1.76
B		1.94	4.24**	4.49**	B		2.84	2.56	0.45
C			2.30	2.55**	C			5.40**	3.34
D				0.25	D				2.11

* = significant at the 0.05% level

** = significant at the 0.01% level

Table 6.--Body temperature of burnt and normal tuna at time of auction (20 September-15 October 1977).

	Burnt	Not burnt
Sample size	11	18
Body temperature (°C)		
Deep	25.45 ± 3.03	25.01 ± 3.02
Superficial	17.40 ± 2.13	18.10 ± 4.11
Average fish weight (lb)	184.64 ± 35.88	197.94 ± 79.40
Sex ratio	6 males : 3 females	16 males : 1 female

Table 7.--The pH of tuna sampled at the Honolulu auction.

	All auction samples		Tail		Deep	
	Burnt	Good	Burnt	Good	Burnt	Good
N	17	5	6	1	4	2
$\bar{x}$	5.78	6.12	5.8	6.1	5.76	6.2